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# Microclimate Studies on a Group Selection Silvicultural System in a High-elevation ESSFwc3 Forest in the Cariboo Forest Region

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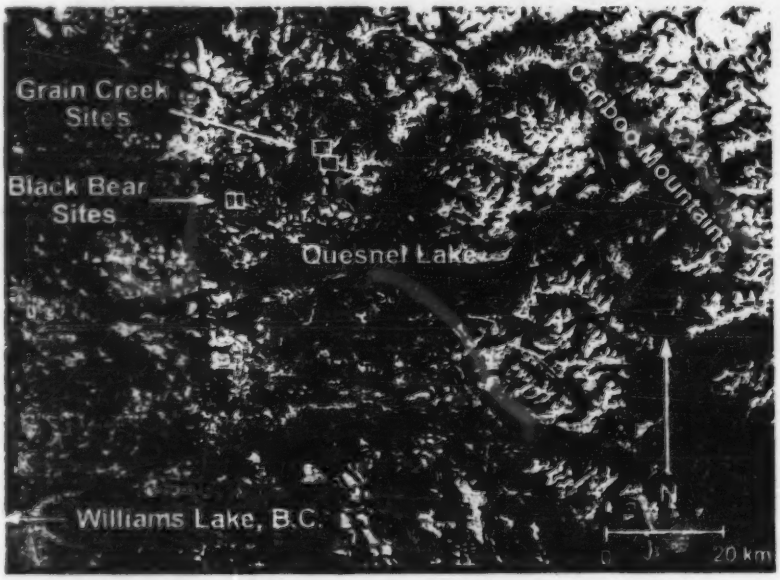


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# Microclimate Studies on a Group Selection Silvicultural System in a High-elevation ESSFwc3 Forest in the Cariboo Forest Region

Robert J. Stathers, Teresa Newsome,
Michaela J. Waterhouse, and Craig Sutherland

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**ABSTRACT**

Microclimate measurements were collected from 1993 through 1998 in an uncut control, 0.03, 0.13, and 1.0 ha (20, 40, and 113 m diameter) group selection openings, and a clearcut at three sites in the ESSFwc3 in the Cariboo Forest Region. Near-surface soil and air temperatures were also monitored in a variety of conifer seedling planting microsites in each of these treatments.

Macroclimate has a large effect on microclimate at these cold, wet, high-elevation ESSFwc3 sites. For 7 months of the year, the ground is covered with a deep snowpack. The short growing season lasts from early June through late October. Air temperatures are highly variable during the growing season as a continuous series of Pacific frontal systems strongly influence local weather conditions. Average daily air temperatures typically range from 5 to 15°C during the mid-summer. Extended rainless periods of up to a month can result in warmer weather when temperatures can exceed 25°C. During the winter the air temperature typically ranges between 0 and -10°C, but can drop below -35°C when cold arctic air masses push southward.

Frequent precipitation is characteristic during the growing season. Afternoon convective rainshowers of 1–10 mm typically occur 3–5 times per week and frontal systems often occur with up to 40 mm of rainfall. The humid air masses in the ESSFwc3 cool to the dew point at night, depositing dew on the forest canopy. The dewfall and precipitation result in continuous forest canopy wetting and drying cycles. The forest canopy remains dry for approximately 25% of the days during the growing season. The soil profile also remains wet throughout the growing season, drying significantly only during the occasional extended hot rainless periods.

The air temperature at 15 cm above the ground surface was similar between and within openings. Summer frosts as low as -2°C occurred throughout the growing season at all sites. Minimum nighttime air temperatures were highly variable within each opening, and not well correlated with opening size or location. The upper slope position and steep slopes allowed cold air drainage and prevented more damaging frosts.

Rooting zone soil temperatures were near 0°C for most of the year under the deep snowpack. During the growing season, root zone (15 cm) temperatures typically remained between 6 and 12°C, and increased to as much as 16°C during hot, dry periods. Approximately 400–600 degree days (5°C) normally accumulated during the growing season, although this varied considerably from year to year, depending upon the weather conditions and when the deep snowpack melted.

Soil profile and near-surface air temperatures and accumulated 5°C degree days were found to increase with increased forest canopy opening size. The accumulated degree days were found to nearly double in the clearcut compared with the uncut forest. Planting microsites also had different soil thermal regimes. Microsites that were raised or had exposed mineral soil tended to have increased degree day accumulations.

We would like to thank Nola Daintith, Lyn Konowalyk, Helen Farrer, Craig Smith, and Lanny Englund for assisting with data collection; Harold Armleder for initiating and planning of the project; and Pat Teti, Ordell Steen, and Ken Soneff for reviewing the document in-house. Thanks to Bob Sagar, Dave Spittlehouse, and Mike Jull for external reviews. Funding was provided for the project through the Forest Renewal BC research program.

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Clearcutting has been the predominant silvicultural system for managing high-elevation Engelmann Spruce–Subalpine Fir (ESSF) forests (Steen and Coupé 1997) in British Columbia for the past few decades. Recently, integrated forest management practices have had to become more sophisticated to meet market demands, environmental concerns, and other important resource uses that have been identified in these forests (Armleder and Stevenson 1994).

In the Cariboo Forest Region, a resource use conflict has been identified where clearcut harvesting of high-elevation forests changes the winter habitat for mountain caribou populations (Stevenson et al. 1994). In order to maintain suitable caribou habitat, old-growth forest characteristics must be preserved to maintain an adequate food source of arboreal lichens (*Alectoria* spp. and *Bryoria* spp.). Clearcutting eliminates this important winter food supply for many decades because lichen has been found to be slow to disperse and re-establish on young trees in the more open clearcut environments. Impacts on caribou habitat were not a serious concern when timber production was initiated in the ESSF; however, as the harvested area has increased, the impact on the caribou herd has become potentially more significant.

Several other concerns related to clearcut harvesting and artificial regeneration of ESSF forests have been expressed in the past decade. These include aesthetic impacts, various environmental impacts, and concerns about regeneration success, particularly on higher-elevation sites. The importance of aesthetic values such as landscape visual quality in high-elevation transportation corridors has led resource managers to consider other silvicultural systems for these areas. Environmental impacts (such as smoke emissions from prescribed burning, herbicide use for vegetation management, watershed impacts for downstream water users and fish, impacts on wildlife and bird populations, long-term site productivity, and site degradation from harvesting operations) have also been identified as issues of concern. This does not necessarily imply that the clearcut silvicultural system is inappropriate for the ESSF, but rather that the application of this treatment on all sites may not meet the objectives of integrated forest management for the entire zone.

The group selection silvicultural system may be a feasible alternative for managing high-elevation forests. The forest attributes retained by a group selection silvicultural system might maintain suitable caribou habitat, allow for some level of timber extraction, and address the issues of aesthetics, environmental impacts, and regeneration. Unlike clearcutting, the group selection system could potentially support the continued growth of lichen by maintaining old-growth characteristics at a stand level. At the same time, this system would also allow for a certain level of timber extraction without reducing visual quality objectives below acceptable limits. Since a group selection system relies heavily on natural regeneration, many of the issues related to clearcutting and artificial regeneration practices (such as smoke emissions, mechanical site preparation, herbicide treatments, and site degradation) may also be alleviated.

The primary objective of this research project was to determine whether group selection silvicultural systems were a viable forest management system that would provide the basis for an economical harvesting system while also

maintaining suitable caribou habitat. In order to achieve this, the specific objectives of the research were (1) to assess whether the group selection system was viable for maintaining caribou habitat and old-growth stand characteristics, (2) to assess whether a group selection system would minimize the risk of blowdown and the incidence of pests and diseases, (3) to assess the effectiveness of natural and artificial regeneration treatments, (4) to assess the effects of changes to soils, snow accumulation and melt, small mammal populations, and bird populations, and (5) to provide extension materials in the form of demonstration sites, research reports, and high-elevation management guidelines for operational foresters.

Microclimate studies were identified as an important component of this research in that the basic data would complement many of the individual studies, particularly the regeneration research and the lichen research. Some of the limitations that affect the successful implementation of any high-elevation silvicultural system were thought to be related to the harsh environmental conditions that occur in the ESSF. Based on previous high-elevation forest research in the province, several environmental limitations have been identified as potentially affecting the outcome of forest management practices. These can be summarized as follows.

High-elevation ESSF forests are typically colder and wetter than the adjacent valley-bottom forests in the ICH and SBS subzones in the Cariboo Forest Region. A deep snowpack begins to develops in late October and does not melt until more than 7 months later in early June. On steeper slopes, the continual creep of the deep snowpack can physically damage and break regenerating trees. Frequent summer precipitation occurs in the Cariboo Mountains in the form of afternoon convective rainshowers or as larger-scale frontal systems pass over the area. The soils remain cold and wet during the early part of the growing season after the snowpack melts and remain suboptimally cool for tree growth even during mid-summer. In lower-lying areas and microsites where cold air and water drainage is concentrated, saturated soils and summer frosts can seriously damage regeneration. Competing vegetation can result in low light levels for conifers or cause vegetation press after the snowpack melts. The relatively short growing season also reduces the potential productivity of trees growing on these sites, and affects their phenology. Certain areas within high-elevation forests can also be prone to a higher windthrow hazard because of their topographic position and edaphic conditions such as shallow and saturated soils. Silvicultural treatments such as the creation of different canopy opening sizes or the use of different site preparation treatments have the potential to create different microclimatic conditions, which would in turn affect lichen and regeneration performance.

The objectives of the microclimate studies were primarily (1) to document the environmental conditions that occur in high-elevation ESSFwc3 forests such that they can be used to explain the effects of silvicultural treatments on regeneration performance and lichen growth, and (2) to examine how different canopy opening sizes, ground surface substrates, and planting microsites influence microclimate conditions. In addition, the data will aid in the interpretation of conifer seed dispersal studies and snow hydrology studies.

This report summarizes the main findings from the microclimate studies and provides background information that should help foresters better understand the environmental conditions that occur in the ESSF.

The overall silviculture systems research project was set up as a randomized complete block design with four treatments: three canopy opening size treatments and an untreated control. This was replicated on three similar ESSFwc3 sites in the Horsefly Forest District. An adjacent 30-ha clearcut was also used for the microclimate studies at Blackbear Creek, where microclimate monitoring was the most intensive.

## 2.1 Site Descriptions

The sites were located at (1) Blackbear Creek (TSL A43738), 3 km north of Spanish Lake, (2) Upper Grain Creek (TSL A43737), approximately 16 km north of Quesnel Lake, and (3) Lower Grain Creek (TSL A43737), approximately 14 km north of Quesnel Lake. Location of the sites is shown on Figure 1. Characteristics of each of the sites are outlined in Table 1.

All of the sites were classified as ESSFwc3; the highest-elevation forested subzone in the eastern Cariboo Forest Region (Steen and Coupé 1997). The Grain Creek sites were dominated (by volume) by subalpine fir mixed with lesser amounts of Engelmann spruce, while the Blackbear sites contained more Engelmann spruce than subalpine fir. The oldest trees ranged from 460 years at Grain Creek to 300 years at Blackbear. The tallest trees were 25-30 m. Stands are generally multi-aged and clumpy. The canopy is more open on the Grain Creek sites and there are several wet subalpine meadows scattered throughout. A shrub-dominant (primarily white rhododendron) understory community had developed on the sites. The gross timber volume over all three sites ranges from 300 to 387m$^3$/ha. All three sites were harvested in the winter of 1992/93. Site preparation was completed in the summer of 1993.

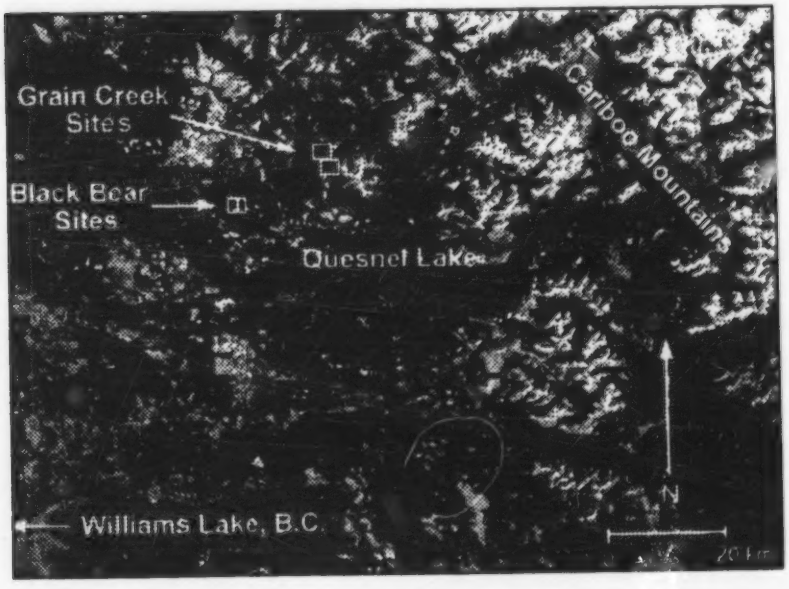


FIGURE 1 *Location of the three trial sites.*

TABLE 1 *Characteristics of the three research sites*

| Feature | Upper Grain Creek | Lower Grain Creek | Blackbear Creek |
|---|---|---|---|
| **Site area (ha)** | 44 | 40 | 61 |
| **Elevation (m)** | 1450–1620 | 1590–1690 | 1450–1610 |
| **Locations** | 52°41'29"N<br>121°12'02"W | 52°40'45"N<br>121°10'52"W | 52°36'37"N<br>121°24'30"W |
| **Slope gradient (%)** | 22–32 | 15–35 | 15–40 |
| **Slope aspect** | W | NW | NE |
| **Soil parent material** | Morainal blanket | Morainal blanket | Morainal blanket |
| **Soil classification** | Orthic Humo-ferric Podzol. 3–15 cm LFH | Orthic Humo-ferric Podzol. 3–15 cm LFH | Orthic Humo-ferric Podzol. 3–15 cm LFH |
| **Dominant tree species** | Subalpine fir<br>Engelmann spruce | Subalpine fir<br>Engelmann spruce | Engelmann spruce<br>Subalpine fir |
| **Inventory label** | BS831P | BS831P | SB(Pl)83M |
| **Dominant understory** | *Rhododendron albiflorum* | *Rhododendron albiflorum* | *Rhododendron albiflorum* |
| **Moisture regime** | Submesic/mesic | Submesic/mesic | Mesic/submesic |
| **BGC classification and series** | ESSFwc3 01 (02) | ESSFwc3 01 (02) | ESSFwc3 01 (02) |

**2.2 Experimental Treatments**

At each of the three sites, the experiment encompassed an area of 40–60 ha. Each of the three group selection canopy opening sizes and the untreated control were laid out across the site contour in approximately similar 10- to 15-ha units. Within each of these treatment areas, group selection units with canopy opening areas of 1.0, 0.13, and 0.03 ha were created by winter logging with feller bunchers and tracked skidders.

Volume removal for the first harvest was approximately 30%, including 4-m-wide skid trails, but not major roads and landings. Skid trails were located perpendicular to the site contours. The openings were roughly circular, with the 1.0-ha treatment having a radius of 56 m, the 0.13-ha treatment a radius of 20 m, and the 0.03-ha opening a radius of 10 m. Given the characteristics of the stand, this translated roughly into treatments with a radius of 2, 1, and 0.5 tree heights. Figure 2 shows the trial layout at the Blackbear Creek site.

**2.3 Microclimate Measurements**

A standard climate station was installed at the plot centre of a 1.0 ha group selection opening at each of the three sites. Data from these stations were used to compare general climatic trends between sites. In addition, comparisons of between-treatment effects (uncut control, 0.03 ha, 0.13-ha, 1.0 ha, and clearcut) were also measured at the Blackbear site.

Microsite soil and air temperature measurements were also collected as part of the regeneration performance studies. In the clearcut and near the centre of the 1.0-, 0.13-, and 0.03-ha openings, separate dataloggers were used to monitor the air temperature at the 15 cm height and the soil temperature at the 15 cm depth on (1) two untreated control microsites, (2) a 50 × 50 cm mineral soil screef, (3) a raised microsite approximately 15 cm high, (4) highly decomposed wood, and (5) the protected low side of a large stump. The

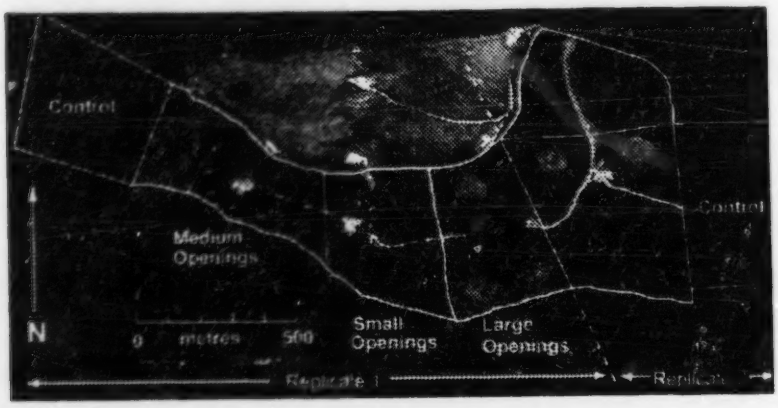


FIGURE 2 *Layout of the three harvesting treatments and the uncut control treatment at the Blackbear Creek Site. Replicate 1 is the winter-logged site where the microclimate was intensively monitored. Replicate 2 is the summer-logged site and not part of the winter-logged replicates*

untreated control probes were located on the average slope conditions and not in a depression or on a raised site. Three of the planting treatments are naturally occuring microsites that may enhance seedling performance. Natural regeneration is often found on decomposed wood or raised microsites in the ESSF, and stumps provide protection from snow creep and snow press. These sensors were intended to provide information about the duration of snow cover, length of growing season, root zone soil temperature, and summer frost severity and frequency to assist in describing the seedling response on these sites.

At each of the standard climate stations on the one hectare opening on all three sites, air temperature and relative humidity were measured (Campbell Scientific Model 207 sensors) in a Stevenson screen, 1.5 m above the ground surface. Three 10 × 10 cm wetness sensing grids (Campbell Scientific Model 237 Leaf Wetness sensors) were installed 3 m above the ground surface in the middle of each plot opening to measure canopy wetting and drying cycles. Differences in the frequency and duration of forest canopy wetting were considered important factors that could likely influence lichen growth. Wind speed (Campbell Scientific Model 014a Anemometer) and direction (Campbell Scientific Model 023 Wind Direction sensor) at the 3 m height, and precipitation (Campbell Scientific Model RG2501 Sierra Tipping Bucket), were also measured in the 1.0-ha treatment.

In the uncut control and the 0.03-, 0.13-, and 1.0-ha treatments at Blackbear Creek, air temperature and relative humidity were measured in Stevenson screens at the plot centre and in the adjacent stand. Three canopy wetness sensing grids were placed horizontally at the 3 m height. Root zone soil temperature and near-surface air temperature were also monitored extensively in each treatment, as described below. Campbell Scientific Model 107 thermistors were used to measure soil and air temperatures.

Based on the assumption that microclimatic conditions would vary with distance from the stand edge (as a result of the influence of the stand edge on the longwave and shortwave irradiances, and through effects on air movement and convective heat transfer), soil and air temperature sensors were

located at the plot centre, at the stand edge, and at 70% of the distance from the stand edge to the plot centre on the north, east, south, and west axes in all opening sizes. An additional probe was added in the 1.0-ha opening at 60% of the distance from the stand edge to the plot centre. It was assumed that the forest edge effect on microclimate probably did not change proportionally with distance from the edge, but probably changed most rapidly from the edge toward the centre in proportion to the direct solar irradiance. Hence, for the 1.0-ha treatment with the 56-m radius, sensors were located at the plot centre (0 m), and at 32, 40, and 56 m from the plot centre. For the 0.13-ha opening with the 20-m radius, sensors were located at the plot centre and at 14 and 20 m from the centre, and for the 0.03-ha opening with the 10-m radius, sensors were located at the plot centre and at 7 and 10 m from the centre. The air temperature at the 15 cm height and soil temperatures at the 1 and 15 cm depths were measured at the plot centre and at each of these treatment measurement locations on the north, east, south, and west axes of each plot.

Temperatures were measured with unshielded thermistor sensors, designed to withstand the deep snow pack, snow creep, and vegetation press. The 15 cm height air temperature sensors were placed in a horizontal position relative to the ground, potted with clear epoxy resin, and not shielded, in order to emulate the radiative characteristics of planted conifer seedling stems. As a result, daytime maximum temperatures indicated by these sensors might have exceeded the adjacent air temperature by a few degrees on hot sunny days due to radiative heating. Similarly, nighttime minimum temperatures would be less than the adjacent air temperature by up to approximately 1°C due to radiative cooling of the sensor surface. It should be recognized that the air temperatures quoted throughout this report were assessed using these methods. They can be considered to be the temperature of the sensor in the air at the 15 cm height above the ground. Similarly, the canopy wetness measurements quoted are inferred from the leaf wetness sensor measurements and are not an exact indication of the canopy water content. These surrogate measurements provide useful relative comparisons between treatments.

All measurements were sampled once per minute with Campbell Scientific Model CR10 data loggers. Average, maximum, and minimum values were recorded on a daily basis. Climate data were collected from the fall of 1993 through 1998.

## 3 RESULTS AND DISCUSSION

### 3.1 General Climatic Conditions at the Three Research Sites

Climatic conditions in the ESSF are determined primarily by the characteristics of the overlying air masses and secondarily by site-specific features such as elevation, slope position, slope aspect, slope gradient, soils, and vegetation cover. Air masses have generally similar temperature and humidity conditions and typically cover areas ranging from hundreds to thousands of square kilometres. The characteristics of the air masses are determined by global atmospheric circulation patterns and constantly change as weather fronts move in from the Pacific and arctic regions. The high- and low-pressure weather systems evolve over periods lasting from less than a day to as long as a month; however, they typically have a duration of about 1–3 days. The

overlying air masses largely influence the local atmospheric temperature and humidity, the amount of precipitation received, and the wind speed and direction.

Local landscape features such as the Cariboo Mountains also have an influence on the generally eastward-moving air masses. As the air orographically lifts over the mountains, the air temperature decreases and the relative humidity increases. Orographic lifting results in cumulus cloud development if the atmospheric humidity is high. This, in turn, causes late afternoon rainshower activity, particularly on the windward side of the mountains.

Site-specific features influence local microclimatic conditions through their effects on the surface energy and water balances, solar and longwave irradiances, concentration or dilution of water flow and near-surface air flow, and characteristics that influence the receipt and storage of energy and water within the soil profile. Biologically significant variations in microclimate occur near the ground surface as a result of the site-specific characteristics and forest management practices. There can be large spatial variability in microclimatic conditions within short distances. Microclimates can also change over time as vegetation cover changes.

The following sections of this report illustrate these general concepts by showing that the climatic conditions are quite similar between sites and that the general climatic patterns are also remarkably similar from year to year. However, certain silvicultural treatments (such as creating different canopy opening sizes, or planting into a variety of microsites) are shown to influence microclimate conditions.

**3.1.1 Screen height air temperature** A typical course of daily air temperature variation in the ESSFwc3 over a period of 5 years is shown in Figure 3. The similarity in the pattern of temperature variation over the course of a year and from year to year is particularly evident in this graph. The general trend is sinusoidal, in direct response to the annual variation in solar radiation; however, the air temperature wave lags behind the solar irradiance by 4–6 weeks. For example, total daily solar irradiance is at a maximum at the June solstice, yet maximum air temperatures occur later in the summer. Daily temperature variation is also greater in the summer than in the winter because of the increased solar irradiance.

The duration of weather systems or similar air masses can be seen in the air temperature behaviour, as evidenced by periods of similar daily patterns in Figure 4. Note how large temperature and humidity changes accompany frontal weather systems. This can also be seen for the same site and time frame by using the relative humidity and precipitation data presented in Figure 6. These two figures together illustrate the linkage between air temperature, relative humidity, and precipitation in the ESSF during a typical growing season.

During the summer the air temperature typically varies throughout the day from lows of 0–5°C to highs of 15–20°C. In the winter, the air temperature typically varies diurnally from lows of -15 to -8°C to highs of -5 to 0°C. Cold arctic air masses that envelop the region for periods of a few days each winter can result in temperatures dropping below -30°C.

Another significant feature of the climate throughout most of British Columbia is a typical period of hot, dry weather, which can last for 10–30

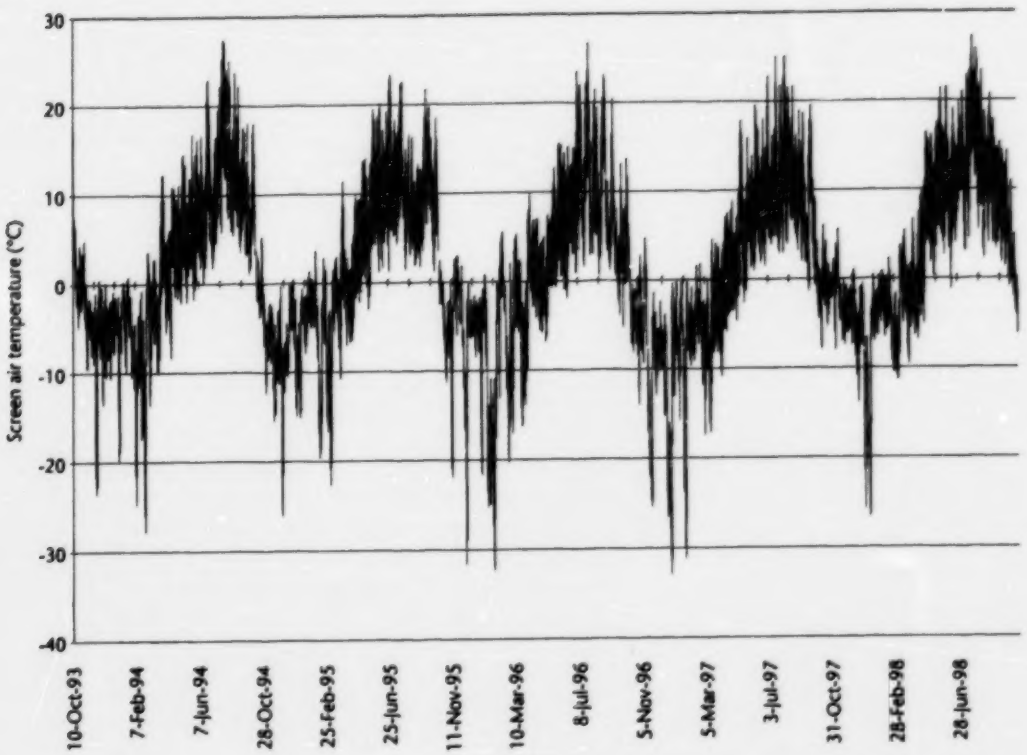


FIGURE 3 *Air temperature range, with each bar showing the daily maximum and minimum temperatures at screen height (1.5 m) from 1993 to 1998, in the uncut control treatment at Blackbear Creek.*

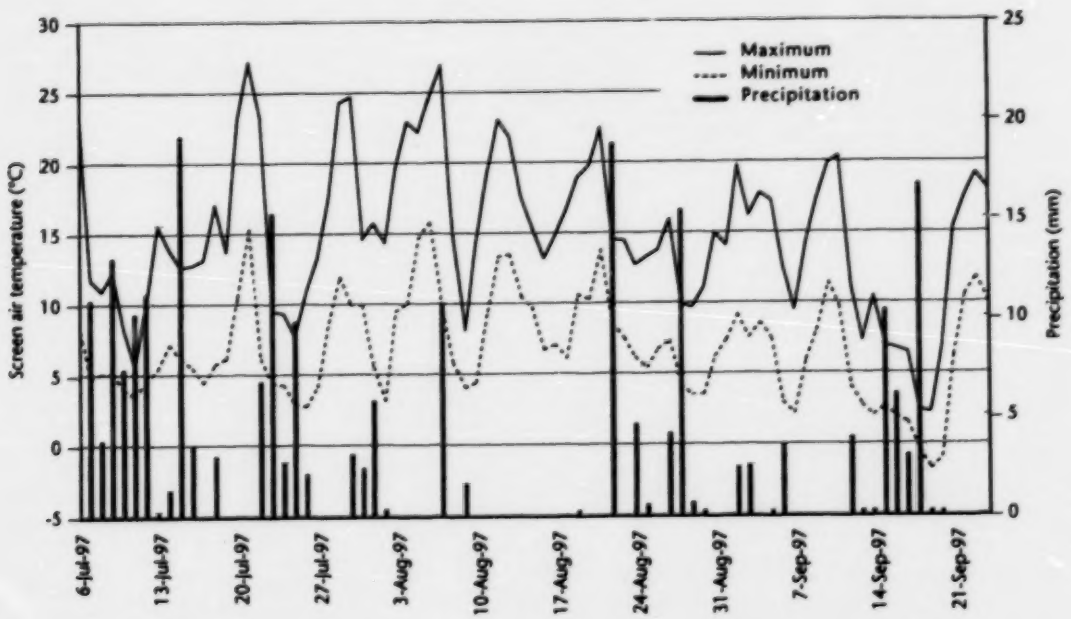


FIGURE 4 *Air temperature (lines) and precipitation (bars) patterns in the 0.13 ha group selection treatment at Blackbear Creek during the 1997 growing season. Note the comparison with Figure 6.*

consecutive days during the mid to late summer. When these weather conditions persist for more than about 3 weeks, soil water deficits can cause widespread mortality to recently planted conifer seedlings, although serious water deficits are rare in the wetter ESSF subzones.

A comparison of the accumulated growing season degree days for each of the three research sites is given in Table 2. An accumulated growing degree day is a heat sum or integral of the total heat input over a given time period. It is calculated by subtracting 5°C from the daily average screen air temperature and accumulating this value for the period from May 1 through September 30.

Some important trends can be seen from the data in Table 2. First, the variation in accumulated degree days was less than 5% between sites in any given year. This indicates that meso- and macroscale weather patterns play a significant role in determining atmospheric climatic conditions within similar biogeoclimatic subzones. Second, the annual variation in degree days within sites was high. For example, at Blackbear Creek the average annual accumulated degree days was 622 (std.dev.=156) and the annual variation was as high as 42%. During the relatively cool year of 1996 when the snowpack melted later than usual, fewer than 500 degree days were accumulated, while during the relatively hot, dry 1998 growing season, almost 900 degree days were accumulated.

**3.1.2 Precipitation** The ESSFwc3 is a relatively wet subzone compared with the other biogeoclimatic units in the Cariboo Forest Region. A comparison of the total precipitation from June 1 through September 30 from 1994 through 1998 for all three sites is outlined in Table 3. There is a considerable variation in precipitation both from year to year and from site to site. The annual variation in precipitation is similar to the air temperature behaviour. Differences in precipitation between sites are due to the convective rather than frontal nature of summer storms.

TABLE 2 *Accumulated growing season (May 1–Sept. 30) screen air temperature 5°C degree days from 1994 to 1998 at the three research sites in the 1.0- ha openings*

| | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| Upper Grain Creek | - | 620 | 484 | 563 | 865 |
| Lower Grain Creek | - | 595 | 499 | 589 | 874 |
| Blackbear Creek | 617 | 562 | 472 | 573 | 884 |

TABLE 3 *Total growing season precipitation (mm) (May 1–Sept. 30) from 1994 to 1998 at the three research sites*

| | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| Upper Grain Creek | - | 177 | 378 | 362 | 190 |
| Lower Grain Creek | - | 228 | - | 267 | 175 |
| Blackbear Creek | 291 | 158 | 345 | 238 | 186 |

Frequent summer precipitation is a significant characteristic of the climate of the ESSFwc3. This occurs as a result of afternoon convective rainshower activity and from moist low-pressure frontal systems that track across the province from the west. During the growing season, the regional air flow is predominantly from west to east. As the air is orographically lifted over the Cariboo Mountains, the temperature decreases by about 0.5–1°C per 100 m increase in elevation. This reduction in air temperature increases the relative humidity. If the air mass was initially moist and if the cooling results in the air reaching its saturation vapour pressure as it rises, then cumulus clouds tend to form. These conditions often result in late-afternoon convective precipitation storms. These rainshowers are of short duration and typically tend to produce 5–15 mm of rain.

Figure 5 shows a frequency distribution of the precipitation at Upper Grain Creek for the period June 1 through September 30, 1996. A total of 378 mm of rain fell during the 122 days of this typical growing season. Precipitation was recorded on 64 (52%) of these 122 days. Most of the rainfall occurred as convective rainshowers of less than 15 mm on 59 days. Only five major frontal weather systems had a total daily rainfall exceeding 20 mm.

Late-afternoon convective rainshowers are one of the climatic features that differentiate the ESSFwc3 from adjacent lower-elevation subzones. Convective shower activity is less common on the lower-elevation sites.

The precipitation regime in the ESSFwc3 is largely a function of topographic position. Forest management practices are unlikely to significantly affect the total amount of precipitation received during the growing season. However, forest management practices can have a very significant influence on site hydrologic conditions through effects on forest canopy interception, evapotranspiration, soil profile water storage, and soil drainage. For any given site, a clearcut would have a much different water balance than an uncut or partially cut forest. Given the high frequency of precipitation

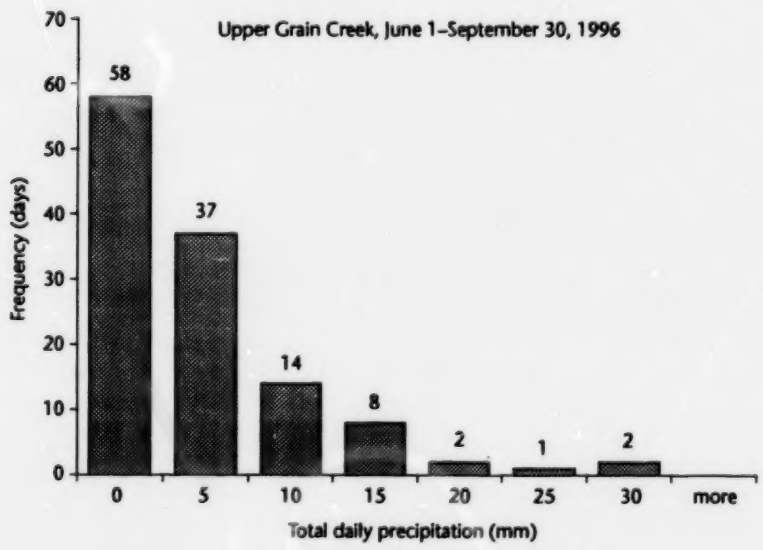


FIGURE 5 *A frequency distribution showing the number of days during the 122-day growing season with total precipitation amounts shown in 5-mm classes.*

events during the growing season, soil water deficits that might affect conifer regeneration are unlikely on these three ESSFwc3 sites.

**3.1.3 Relative humidity** The atmospheric relative humidity follows similar trends to that of precipitation and air temperature, in that it is largely determined by the properties of the large-scale overlying air masses. Each air mass tends to have quite a different temperature and moisture content. As the air masses continually change with the passage of weather fronts, the water content of the air changes, and as a result, the relative humidity changes.

The relative humidity is simply the ratio of the amount of water vapour in the air relative to the maximum amount of water vapour that the air could hold at any given temperature. The maximum water vapour pressure of the air increases with temperature. Hence, as the air temperature rises and falls over the course of a day, the relative humidity changes correspondingly by decreasing during the hottest part of the day and then increasing as the air cools at night. If the water vapour content of the air is high, typical nighttime cooling rates cause the humidity to increase to the saturation vapour pressure. At saturation—the maximum water vapour content that the air can hold at a given temperature (also known as the dew point temperature)—the relative humidity is 100%.

On most of the nights during the growing season in the ESSFwc3, enough atmospheric cooling occurs for the humidity to rise to 100% and for dewfall to occur. This is illustrated in Figure 6, where a plot of daily maximum, minimum, and average relative humidity is given for part of the 1997 growing season in the 0.13 ha group selection treatment at Blackbear Creek. Also

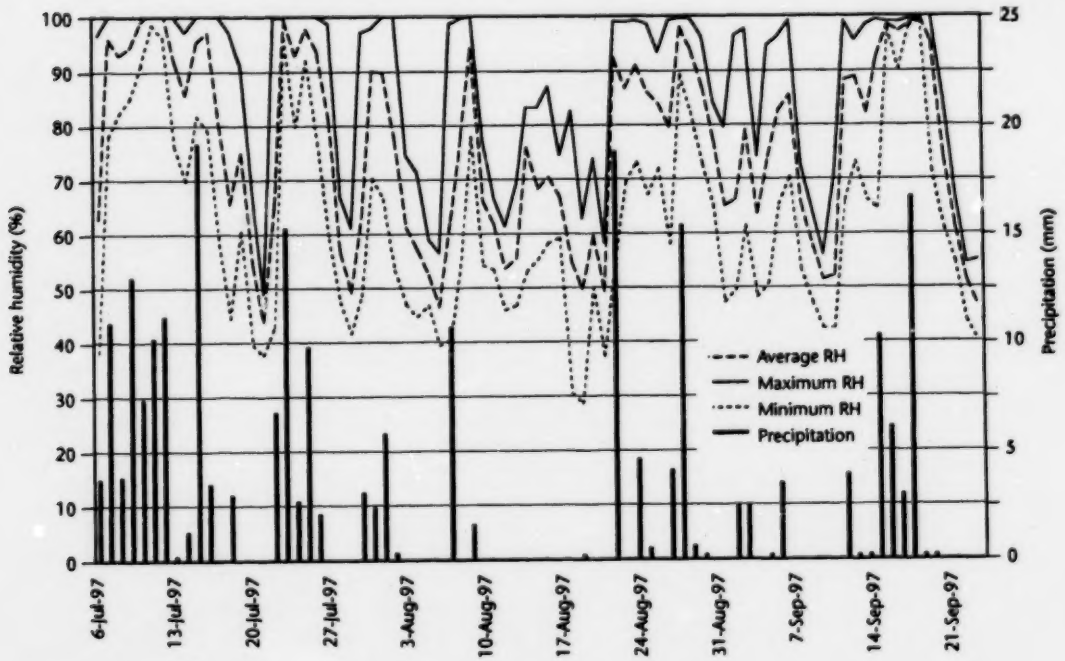


FIGURE 6 *Relative humidity (lines) and precipitation (bars) patterns in the 0.13 ha group selection treatment at Blackbear Creek during the 1997 growing season. Note the comparison with Figure 4.*

shown on this graph is the total daily precipitation. It is evident that, on days when rainfall occurred (when the atmospheric water vapour content was high), the relative humidity typically rose to 100% at night. During extended rainless periods when the overlying air mass was relatively dry and warm, the relative humidity did not rise to 100% because the air temperature did not cool to the dew point temperature. Note that a smaller temperature change is required for a warm, wet air mass to cool to the dew point than for a cold, dry air mass.

The significant feature of this air temperature, relative humidity, and precipitation relationship is that the relative humidity approaches 100% on most nights in the ESSFwc3. As a result, dewfall occurs frequently at night during the growing season. Frequent canopy wetting and drying cycles resulting from precipitation and dewfall are important ecological characteristics of the ESSF that have allowed arboreal lichens to develop in this environment.

Forest management practices such as creating different canopy opening sizes are likely to have a very small effect on relative humidity, since it is largely determined by the characteristics of the overlying air mass and much less by local microclimatic conditions. Even though forest canopy transpiration increases the water vapour content of the air, the transpiration rate is very slow compared with the canopy ventilation rate. As a result, the air within the forest canopy is exchanged very frequently and takes on the characteristics of air above the canopy. Forests often feel more humid than adjacent clearings; however, this is not actually the case. The relative humidity is usually very similar in both locations. Conditions within the forest might tend to feel cooler and more humid because of the reduced level of solar radiation heating the human body.

Figure 6 also illustrates the dynamics of typical growing season air masses. During the early and late part of the growing season there is a constant change in weather conditions, with frequent frontal activity punctuated by periods of only a few days of clear, warm weather. During the mid-summer when high-pressure systems tend to establish for longer periods, hotter, drier weather conditions can last for many consecutive weeks.

**3.1.4 Forest canopy wetness** Forest canopy wetting and drying cycles are thought to be important for lichen dispersal, growth, and development. Forest canopy wetness is strongly influenced by precipitation, relative humidity, and, to a lesser extent, air temperature. The canopy wetness figure outlined below has been selected for comparison with the precipitation, humidity, and temperature figures outlined above and should be read in context with the discussion outlined in those sections above.

Canopy wetness sensing grids were used to determine the proportion of time during each day when the forest canopy remained wet as a result of precipitation or dewfall. As indicated above, frequent convective precipitation and a high frequency of nights when the air temperature falls to the dew point occur in the ESSFwc3. Figure 7 shows the proportion of each day throughout the growing season that wetness sensing grids remained wet. As with precipitation and relative humidity, there was a direct correlation between air mass characteristics and duration of canopy wetting. On most days during the growing season, the wetness sensing grids indicated that the canopy typically remained wet for between 20 and 60% of the day. Only during extended rainless periods in the mid-summer did the forest canopy remain dry for more than a few days.

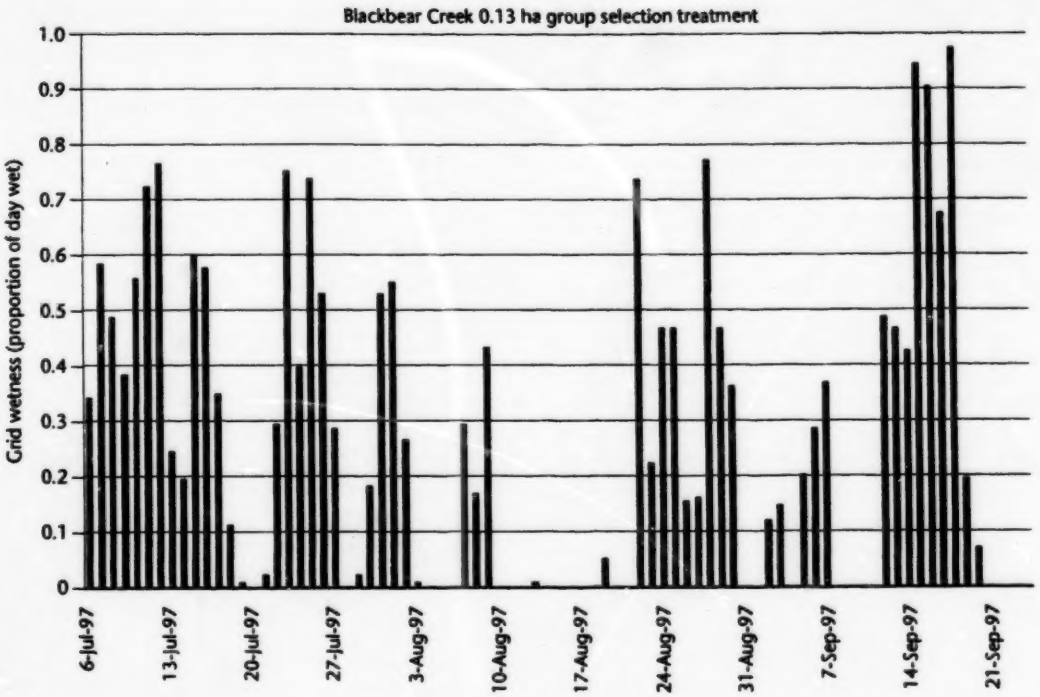


FIGURE 7 *The proportion of each day during which the wetness grids remained wet at Blackbear Creek during the 1997 growing season.*

The canopy wetness data from Figure 7 are also shown in histogram form in Figure 8. During the 122-day growing season period between June 1 and September 30, the canopy remained completely dry on 34 separate days (28%). On 20 days it was wet for 0–3 hours per day, and on 16 days it was wet for 3–6 hours per day. On only a few days during the growing season did the canopy remain wet for the entire day.

Very similar wetting and drying conditions were observed in all treatments and at all three research sites. The canopy grid wetness sensors, located in the plot centres, may have dried more rapidly than the foliage in the adjacent forest canopy. However, these sensors do indicate that considerable wetting and drying occurs on these sites.

3.1.5 **Seedling height air temperature** Seedling height air temperature measured at 15 cm is influenced by all of the climatic factors that influence screen height air temperature as discussed above. However, considerably greater temperature variation can occur near the ground surface where microsite effects (such as a reduction in wind speed, shading by vegetation, or cold air accumulation) occur. As a result, near-surface air temperatures are typically warmer during the day and cooler at night than screen height air temperatures, particularly on clear days and nights.

Figure 9 shows the course of daily average and minimum air temperatures at the 15 cm height from 1993 to 1998 in the control planting microsite in the centre of the 1.0 ha group selection opening at Blackbear Creek. During the winter when the temperature sensor was buried under the snowpack, the

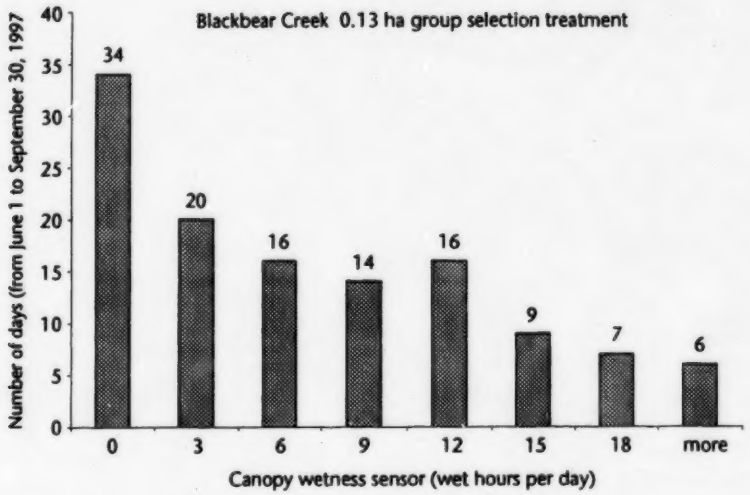


FIGURE 8 *A histogram showing the number of days during the 122-day growing season (between June 1 and Sept. 30, 1997) when the forest canopy remained wet for 0, 0–3, 3–6, 6–9, 9–12, 12–15, 15–18, and >18 hours per day in the 0.13 ha group selection treatment at Blackbear Creek.*

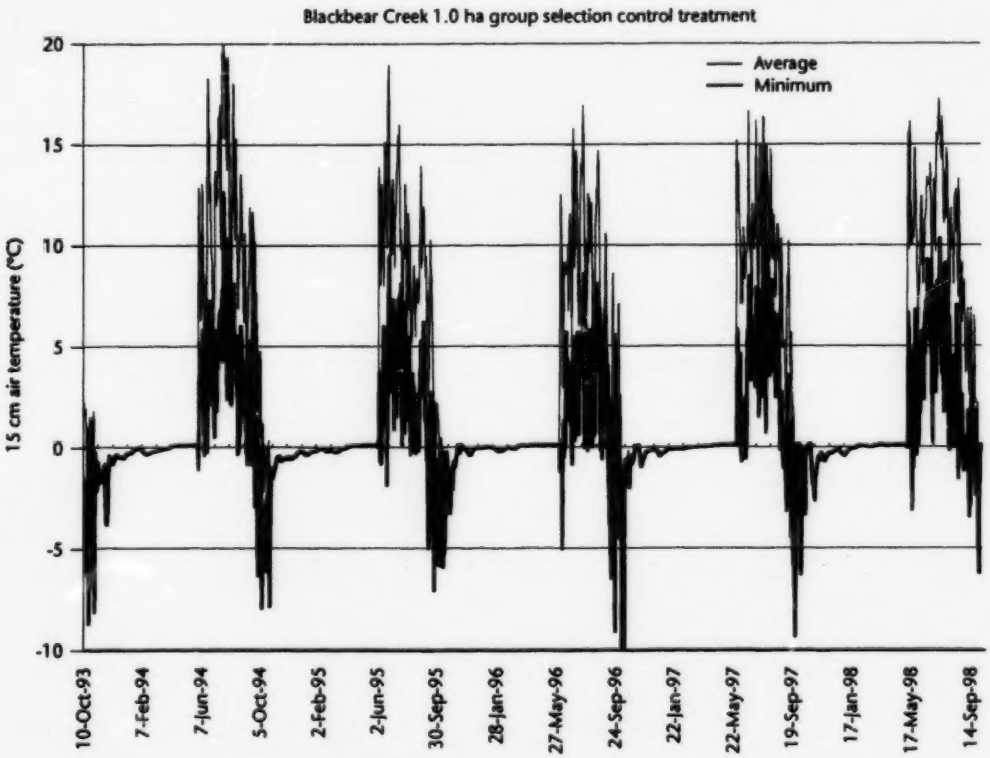


FIGURE 9 *The course of daily average and minimum air temperatures at the 15 cm height from 1993 to 1998 in a control planting microsite in the 1.0 ha group selection opening at Blackbear Creek. Note the length of the winter season.*

temperature was near 0°C. Near-surface air temperatures in the other treatments and at the other sites were similar to those shown below.

A comparison of the accumulated 5°C growing degree days calculated with 15-cm air temperatures from the probes at the centre of all the treatments from 1994 to 1998 at Blackbear Creek is shown in Table 6. Though there was considerable year-to-year variation (and variation from sensor to sensor) there is a trend between accumulated degree days and opening size. For example, from May 1 through September 30, 1997 the accumulated degree days increased with opening size. In the uncut control, and in the 0.03-ha, 0.13-ha, 1.0-ha, and clearcut openings, accumulated degree days calculated from the control #2 probe were 500, 417, 550, 561, and 673, respectively.

**3.1.6 Summer frost frequency and severity** Summer frost events occurred every summer in every treatment at each of the three research sites. Figures 9 and 10 show the typical courses of the minimum daily seedling height air temperature in the control planting treatment at Blackbear Creek and Upper Grain Creek. Opening size appeared to have relatively little effect on the minimum temperature; therefore, only the 1.0 ha openings are presented. Note that under the snowpack the temperature remained near 0°C.

Minimum temperatures of -2 to -3°C occurred frequently from the time the snowpack melted until late June. During July and August, minimum temperatures were typically above freezing; however, on occasion the temperature would drop to a low of -1 or -2°C. Only in early September did colder night temperatures re-occur. Summer frosts usually must be colder than -4°C before significant damage occurs to recently planted Engelmann

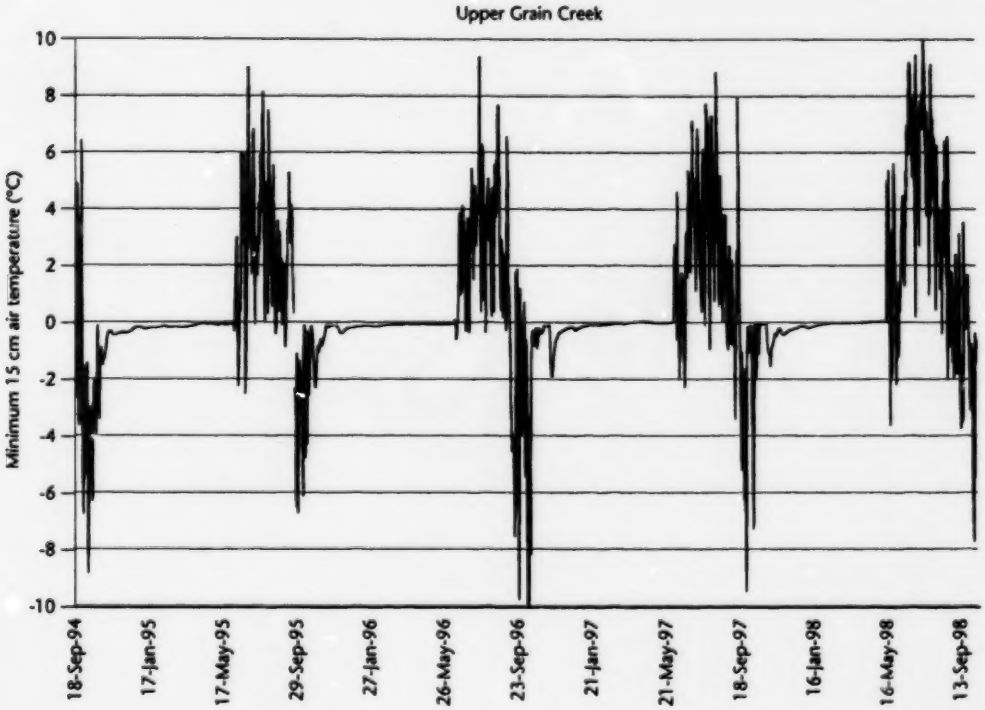


FIGURE 10 *Daily minimum air temperatures at the 15 cm height from 1994 to 1998 in an untreated microsite in the 1.0 ha group selection opening at Upper Grain Creek.*

spruce and subalpine fir seedlings. The summer frost hazard would be considered moderate on ESSFwc3 sites in upper slope positions with slope gradients in excess of 10–15 degrees, such as found at these research sites. Microsites within these sites where downslope cold air flow would be concentrated or collected would very likely have a high summer frost hazard and experience temperatures as low as -6°C during mid-summer.

**3.1.7 Root zone soil temperatures** Root zone soil temperatures are determined by surface energy and water balances. As a result, they are most affected by solar irradiance, atmospheric weather conditions, and soil profile characteristics. Thus, site-specific factors that influence the surface energy balance characteristics (particularly the solar irradiance) or the thermal properties of the soil profile can significantly modify the soil temperature regime. This is in contrast with atmospheric climatic conditions such as air temperature, humidity, precipitation, and wind speed that are macro-scale properties of air masses that are not changed by forest management practices. Consequently, harvesting treatments, vegetation management treatments, and planting treatments can have a significant effect on the soil thermal regime.

The deep snowpack in the ESSFwc3 has a large influence on the soil thermal regime, as shown in Figure 11. For 7 months of the year (late October through late May) snow cover acts as an effective insulator, which largely decouples energy transfer between the soil profile and the atmosphere. The profile rarely freezes, and root zone temperatures remain near 0°C for most of the winter. In adjacent drier subzones, with less snowfall, the soil profile tends to freeze throughout the root zone during the winter and also tends to

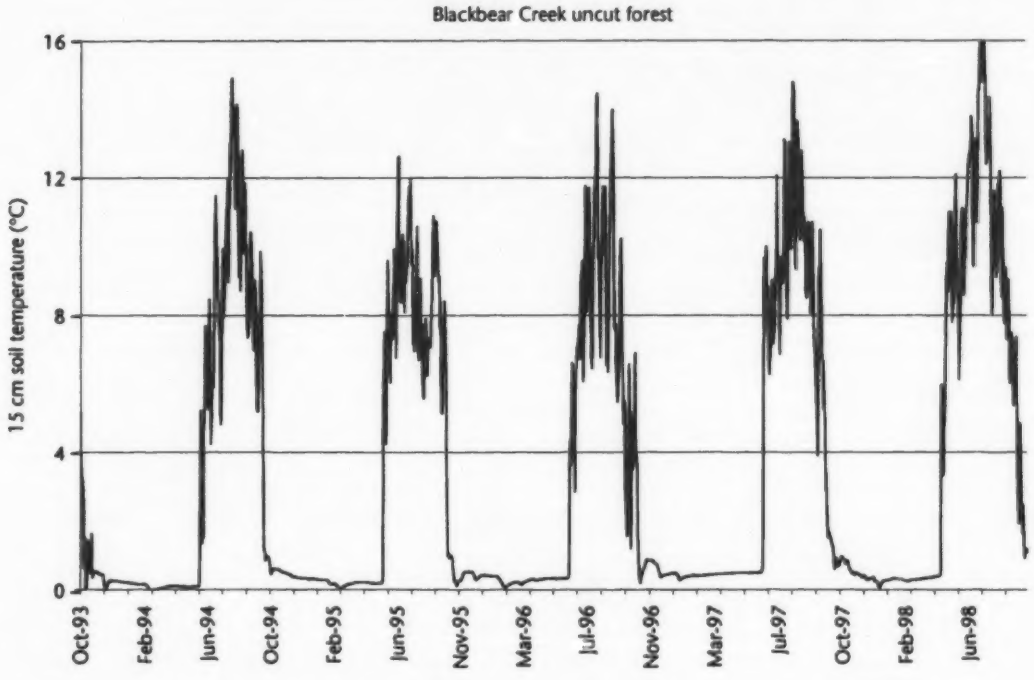


FIGURE 11 *Average daily soil temperature at the 15 cm depth in the uncut forest control treatment at Blackbear Creek between 1993 and 1998.*

warm up earlier in the spring because less energy is required to melt the shallower snowpack.

Hydrologic studies at these sites have also indicated that the dates on which 50% of the ground was snow-free from 1994 through 1998 varied from mid-May to the first week in June. There were no clear differences in this date between forest and openings (P. Teti, pers. comm., 2000).

As soon as the snowpack melts, the 15-cm soil temperature increases rapidly and remains between 5 and 10°C for most of the growing season. During extended warm, dry periods in July and August, root zone temperatures can increase to 15–20°C; however, they rapidly drop below 10°C as cold rainfall percolates through the profile.

Even though root zone soil temperatures appear to be quite similar from year to year, there can be considerable differences in accumulated degree days. Table 4 shows the accumulated growing season (May 1–September 30) 15-cm soil temperature 5°C degree days from 1994 to 1998 measured in the middle of the 1.0 ha partial cut treatment at the three research sites. In 1996, when the snowpack melted later than usual, there were approximately half as many degree days as during a relatively warm year such as 1998, when the snowpack melted earlier. Blackbear Creek, the lowest-elevation site, has had consistently more growing degree days compared to the higher-elevation Grain Creek sites.

Canopy opening size and planting treatments were also found to have an influence on the soil thermal regime. These topics will be considered separately in later sections.

**3.1.8 Date of snow melt** The approximate date of snowpack melt could be determined by examining the daily 15 cm height air temperature amplitude. While under snow, the temperature remained near 0°C; as soon as the pack melted, diurnal temperature variation increased rapidly.

The snowpacks in the 1.0-ha openings at the Upper Grain Creek, Lower Grain Creek, and Blackbear Creek sites generally melted within a few days of each other, except in 1996 when the snow at the Blackbear site melted approximately 2 weeks earlier. The melt date varied by as much as 3 weeks from year to year. Considerably higher soil and air temperature degree day accumulations occurred in an early snowmelt year such as 1998, whereas the opposite effect occurred in a late snowmelt year such as 1996. Much greater air temperature degree day accumulations also occurred in 1998 than in 1996.

The dates presented in Table 5 represent when the majority of the opening was snow-free. The snowpack melted up to 20 days earlier in the clearcut than in the 0.03-ha openings. In general, earlier melt occurred in the two larger-sized openings, as would be expected as a result of the increased direct solar irradiance in the centre of the larger openings. Due to variations in snow accumulations and shading, portions of the large opening became

TABLE 4 *Accumulated growing season (May 1–Sept. 30) 15-cm soil temperature 5°C degree days from 1994 to 1998 in the 1.0 ha partial cut treatment at the three research sites*

| | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| Upper Grain Creek | - | 305 | 254 | 341 | 556 |
| Lower Grain Creek | - | 317 | 260 | 346 | 605 |
| Blackbear Creek | 476 | 511 | 453 | 515 | 639 |

TABLE 5 *Snowpack melt dates from 1994 through 1998 for all three sites and all of the treatments at the Blackbear Creek site*

| | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| Upper Grain Creek | - | June 5 | June 18 | June 10 | May 26 |
| Lower Grain Creek | - | June 6 | June 21 | June 13 | May 29 |
| Blackbear clearcut | - | May 30 | June 1 | May 31 | May 12 |
| Blackbear 0.03-ha opening | June 8 | June 17 | June 21 | June 17 | May 29 |
| Blackbear 0.13-ha opening | May 26 | June 6 | June 7 | June 6 | May 21 |
| Blackbear 1.0-ha opening | June 1 | June 9 | June 10 | June 9 | May 24 |
| Blackbear uncut control | May 23 | May 30 | June 7 | June 6 | May 8 |

snow-free before the medium opening. However, the large opening took approximately 25 days to become totally snow-free, resulting in a later snow-free date compared to the 0.13-ha opening, which took approximately 15 days to melt. Interestingly, the uncut control treatment usually melted considerably earlier than the group selection treatments. This might be explained by the lower snowfall accumulation that would have occurred under the canopy in the control, and by the relatively open forest canopy in this treatment, which would have allowed direct solar radiation to reach the ground surface. Other studies have shown that snowmelt usually occurs later beneath a dense forest canopy than in an adjacent clearcut due to the shading of the snowpack.

**3.1.9 Wind speed and direction** Average daily wind speed typically varied from 2 to 5 m/s (from 7 to 18 km/hr) at Upper Grain Creek, as shown for the fall of 1994 in Figure 12. Late September, October, and November was the windiest time of the year, during periods when strong Pacific frontal systems crossed the region. Maximum daily wind speeds of 8–16 m/s (29–58 km/h) were measured frequently during the fall.

Strong storm systems also occurred in the spring, but much less frequently. On typical summer days, the wind speeds were generally light. Daytime anabatic (up-valley and up-slope) and nighttime catabatic (down-valley and down-slope) wind patterns could be discerned during site visits. Similar conditions were measured at the Blackbear Creek and Grain Creek sites.

The wind direction was typically from the west and south at both Grain and Blackbear creeks. Only occasionally did the wind blow from the north or east. Storm winds were normally from the south and west. None of the research sites was in a particularly high windthrow hazard zone.

## 3.2 Effect of Canopy Opening Size and Microsite Treatments on Temperature

Canopy opening sizes, site preparation treatments, and natural microsites influence soil and air temperatures through their effects on (1) energy and water balances and (2) thermal properties of the soil profile. Removing the forest canopy increases the solar irradiance at the ground surface. This increases heat flow into the soil profile and consequently increases soil profile temperatures. It also increases soil temperature variation.

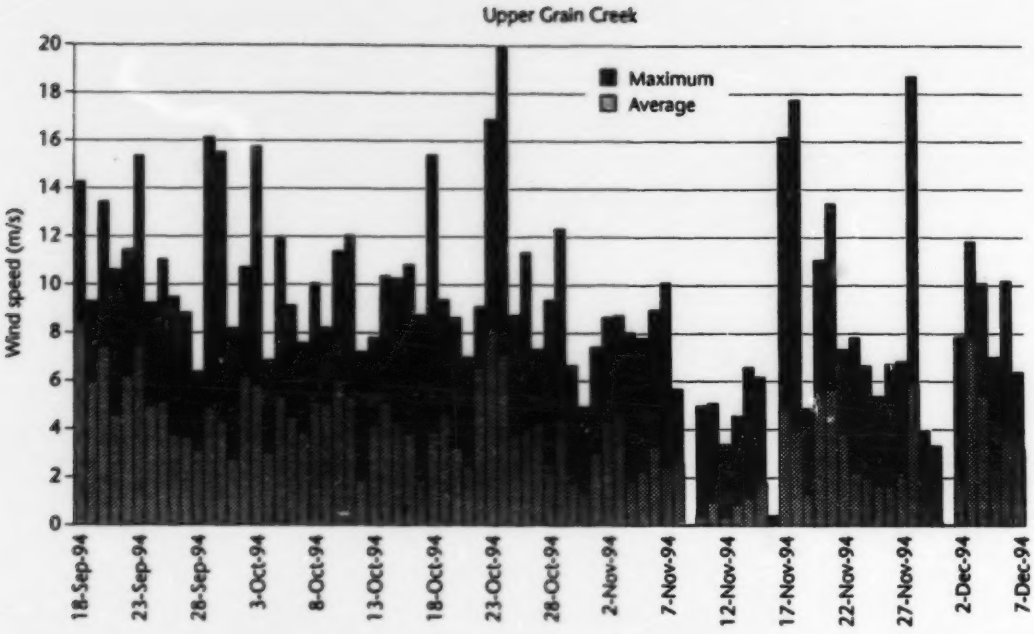


FIGURE 12 *Average and maximum daily wind speed at Upper Grain Creek in the 1.0-ha opening during the fall of 1994.*

Removing the forest canopy increases the soil water content by allowing precipitation to fall to the ground without being intercepted and evaporated on the canopy branches and needles. The thermal properties of wet soils are quite different from those of dry soils. Wet soils have higher volumetric heat capacities and require more surface heat input to increase their temperature. Wet soils also have higher thermal conductivities; hence, when heat enters the soil profile, it is more rapidly conducted away from the warm surface toward the cooler subsurface soil.

Site preparation treatments and various microsites have different thermal regimes because of differences in vegetation cover and soil characteristics. Vegetation shades the surface and cools the soil profile. Organic soil material has markedly different thermal properties than mineral soil, and as a result, a different soil profile temperature distribution. Assuming no vegetation cover to shade the surface, a mineral soil will exhibit less surface temperature variation over the course of a day, and will conduct heat deeper into the profile than an organic soil. Site preparation treatments such as mounding increase the surface area to volume ratio of the soil in the seedling root zone and thus tend to change temperature more rapidly than flat surfaces. Microsites that are deeply shaded by vegetation will tend to show less temperature fluctuation than those exposed to direct sunlight. The previous discussion serves to highlight the fact that many complex and interacting factors affect the soil thermal regime.

Figures 13 and 14 show 15-cm soil and air temperatures, respectively, in control, 50 x 50 cm scalp, and 50 cm diameter raised microsites in the centre of the 1.0 ha group selection treatment in 1994. Unlike air temperatures, which were quite similar between treatments, soil temperatures varied considerably in the microsite planting treatments. During the mid-summer, soil

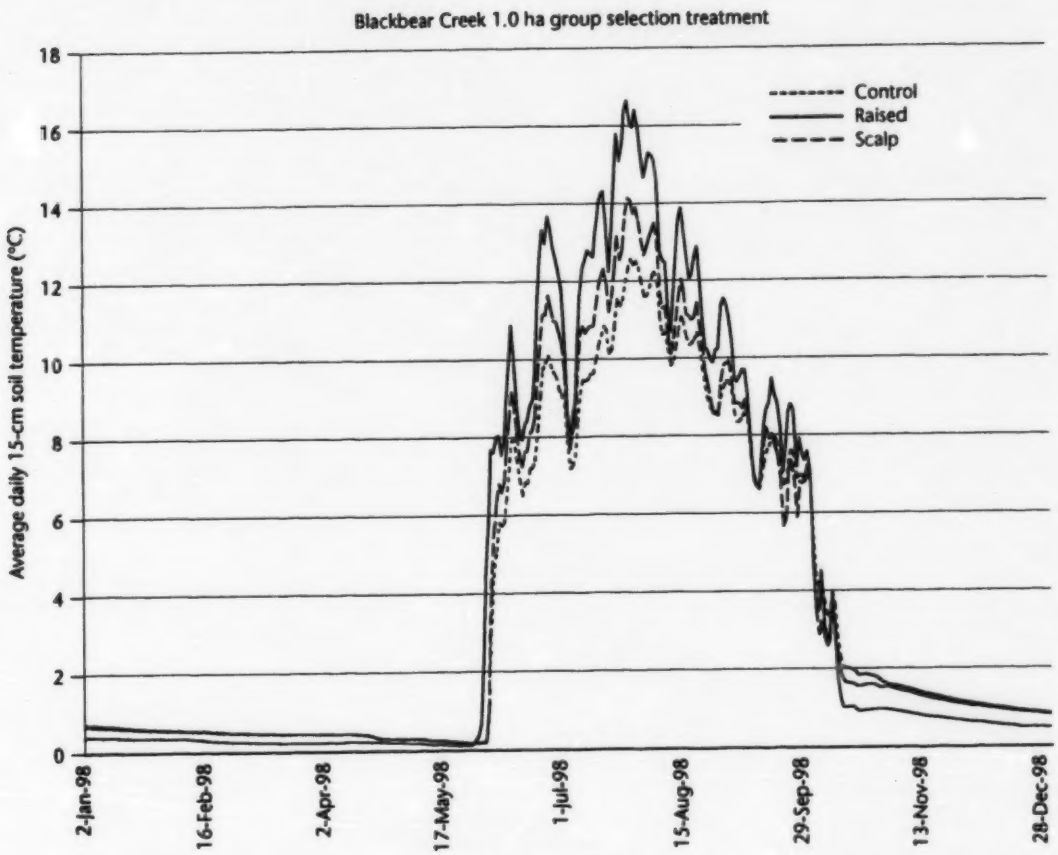


FIGURE 13 *A comparison of average daily 15-cm soil temperatures in untreated control, 50 x 50 cm scalp, and raised microsites during 1994 in the centre of the 1.0 ha group selection treatment at Blackbear Creek.*

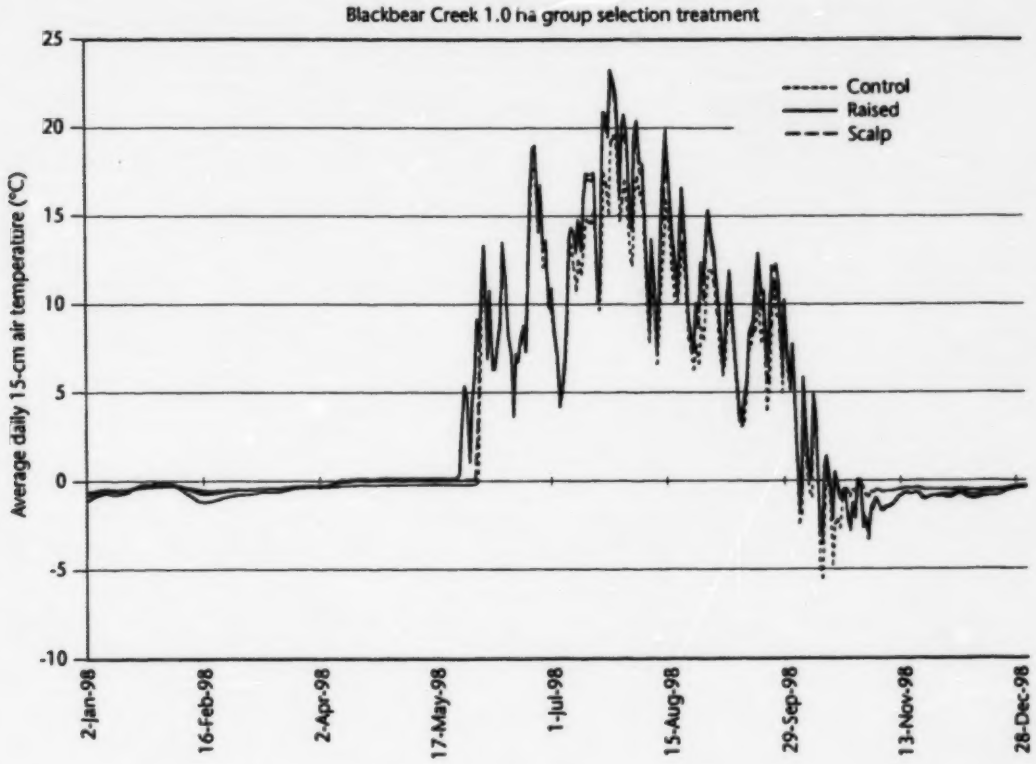


FIGURE 14 *A comparison of average daily 15-cm air temperatures in untreated control, 50 x 50 cm scalp, and raised microsites during 1994 in the centre of the 1.0 ha group selection treatment at Blackbear Creek.*

temperatures varied from about 8–12°C in the control (vegetation-covered) treatment. The scalped treatment, which exposed mineral soil, was typically 1–2°C warmer than the control. The raised microsite treatment was typically 3–4°C warmer than the control. Over the course of the growing season from May 31 through September 30, 1994, degree day accumulations for the control, scalp, and raised treatments were 476, 564, and 727, respectively. Air and soil temperatures were also measured in naturally occurring microsites (a decomposed log and behind a protective stump), where regeneration tends to grow naturally. Temperatures were typically warmer than the untreated control, but cooler than the scalped treatment in these microsites. (Data for these treatments were not shown, to simplify the graphs.)

The same trends were not found in the smaller opening sizes, as shown by the number of degree days in Tables 6 and 7. These tables show the accumulated 5°C growing degree days for each of the canopy opening sizes and microsites from 1994 through 1998 for both 15-cm air and 15-cm soil temperatures. In the 0.13-ha opening, the rotten wood microsite and scalp treatment were as warm as or warmer than the raised microsite. Only the microsite on the lower side of the stump was consistently cooler than the other treatments in both the large and medium openings. Opening size appears to affect climate more strongly than the microsite treatments in the 0.03-ha opening, as trends were inconsistent on the microsite locations.

TABLE 6 *Effect of canopy opening size and microsite treatments on 15 cm height air temperature accumulated 5°C growing degree days (May 1–Sept. 30) from 1994 through 1998. Missing data is indicated with a '-'*

| | Control #1 | Control #2 | Raised | Scalp | Rotten log | Stump |
|---|---|---|---|---|---|---|
| **Uncut control** | | | | | | |
| 1994 | 571 | 570 | - | - | - | - |
| 1995 | 504 | 498 | - | - | - | - |
| 1996 | 474 | 423 | - | - | - | - |
| 1997 | 622 | 500 | - | - | - | - |
| 1998 | - | 792 | - | - | - | - |
| **0.03 ha group selection opening** | | | | | | |
| 1994 | 605 | 575 | 615 | 691 | 615 | 593 |
| 1995 | 437 | 432 | 450 | - | 456 | 450 |
| 1996 | 390 | 391 | 405 | - | 417 | 400 |
| 1997 | 420 | 417 | 420 | - | 442 | 428 |
| 1998 | 692 | 651 | - | 707 | 723 | - |
| **0.13 ha group selection opening** | | | | | | |
| 1994 | 817 | 756 | 827 | 797 | 885 | 820 |
| 1995 | 660 | 561 | 650 | 614 | 706 | 614 |
| 1996 | 580 | 500 | 534 | 541 | 613 | 480 |
| 1997 | 629 | 550 | 587 | 599 | 641 | 579 |
| 1998 | 862 | 852 | 867 | 860 | 868 | 845 |
| **1.0 ha group selection opening** | | | | | | |
| 1994 | 662 | 766 | 866 | 816 | 776 | 734 |
| 1995 | 510 | 564 | 652 | 666 | 630 | 578 |
| 1996 | 453 | 461 | 566 | 598 | 573 | 501 |
| 1997 | 515 | 561 | 642 | 753 | 643 | 549 |
| 1998 | 639 | 738 | 867 | 815 | 742 | 721 |
| **Clearcut** | | | | | | |
| 1994 | - | - | - | - | - | - |
| 1995 | 689 | 882 | 891 | 981 | 847 | - |
| 1996 | - | - | - | - | - | - |
| 1997 | 673 | 732 | 783 | 637 | 809 | - |
| 1998 | 1015 | 1020 | 1123 | 1257 | 1100 | - |

One probe per microsite per opening size does not provide enough replication to account for the amount of variability in temperatures in these locations. However, the data do indicate that some microsites are warmer than others, and that choice of planting location will influence the soil temperatures that a seedling will experience.

There appears to be a weak correlation between opening size and accumulated degree days. The uncut and 0.03-ha openings have a similar average number of degree days, whereas the 0.13-ha and the 1.0-ha openings are similar. The clearcut consistently had the warmest conditions. All the as-

TABLE 7 *Effect of canopy opening size and microsite treatments on 15 cm soil temperature accumulated 5°C growing degree days (May 1–Sept. 30) from 1994 through 1998*

| | Control #1 | Control #2 | Raised | Scalp | Rotten log | Stump |
|---|---|---|---|---|---|---|
| **Uncut control** | | | | | | |
| 1994 | 396 | 404 | - | - | - | - |
| 1995 | 347 | 349 | - | - | - | - |
| 1996 | 337 | 356 | - | - | - | - |
| 1997 | 429 | 296 | - | - | - | - |
| 1998 | 626 | 453 | - | - | - | - |
| **0.03 ha group selection opening** | | | | | | |
| 1994 | 567 | 404 | 441 | 504 | 469 | 420 |
| 1995 | 491 | 314 | 368 | 413 | 379 | 425 |
| 1996 | 449 | 276 | 331 | 371 | 364 | - |
| 1997 | 480 | 308 | 403 | 377 | 414 | - |
| 1998 | 586 | 596 | 619 | 536 | 596 | - |
| **0.13 ha group selection opening** | | | | | | |
| 1994 | 623 | 551 | 593 | 601 | 664 | 512 |
| 1995 | 528 | 443 | 487 | 502 | 572 | 398 |
| 1996 | 504 | 374 | 412 | 474 | 550 | 318 |
| 1997 | 542 | 423 | 395 | 585 | 655 | 399 |
| 1998 | 724 | 607 | 584 | 633 | 738 | 551 |
| **1.0 ha group selection opening** | | | | | | |
| 1994 | 476 | 476 | 727 | 564 | 622 | 551 |
| 1995 | 511 | 369 | 563 | 447 | 502 | 449 |
| 1996 | 453 | 305 | 499 | 402 | 433 | 405 |
| 1997 | 515 | 357 | 557 | 582 | 516 | 520 |
| 1998 | 639 | 494 | 744 | 578 | 641 | 573 |
| **Clearcut** | | | | | | |
| 1994 | - | - | - | - | - | - |
| 1995 | 882 | 701 | 783 | 690 | 628 | - |
| 1996 | - | - | - | - | - | - |
| 1997 | 732 | 749 | 665 | 816 | 540 | - |
| 1998 | 1020 | 1048 | 1261 | 1026 | 794 | - |

sessments were taken at or close to the centre of the openings and these temperatures only reflect the microclimate in that location.

The data shown in Tables 6 and 7 indicate that there is considerable variation in accumulated degree days from year to year. For example, for the untreated control microsite in the 1.0-ha treatment at Blackbear Creek, the degree day accumulations were 766, 564, 461, 561, and 738 from 1994 through 1998. This degree of variation in the annual weather conditions creates variable growing conditions between years.

### 3.3 Effect of Distance from Stand Edge on Air and Soil Temperature

Stand opening size influences the soil and near-surface air temperatures by modifying the energy balance through effects on the solar and longwave irradiances. It also influences the hydrologic balance through effects on precipitation and snowfall interception and the melt rate of the snowpack. The centre of the 1.0-ha plot with the 56 m diameter is much like a clearcut in that it receives direct solar radiation throughout the entire day. Within about a tree height of the stand edge, the ground surface is shaded during a portion of the day, depending upon the aspect. At Blackbear Creek, on a north-facing site with a slope gradient of approximately 25%, the north (lower) edge of the stand received more direct solar radiation than the south (upper) edge of the stand. As a result, the snowpack melted many days earlier and soil temperatures were warmer than on other aspects, as shown in Figure 15.

Soil profile temperatures followed very similar trends in all locations within the stand openings, increasing rapidly after the snowpack melted to average daily values of 10–14°C during July and August. As shown in Figure 16, in the transect from the plot centre to the stand edge on the western side of the stand opening (the east aspect), average daily 15-cm soil temperatures were typically up to 2°C higher at the centre of the opening than on the cooler stand edge. Soil temperatures 32 m from the plot centre were similar to those at the centre because the radiation regime was similar. At 40 and 56 m from the centre, where shading occurred for part of the day, soil tempera-

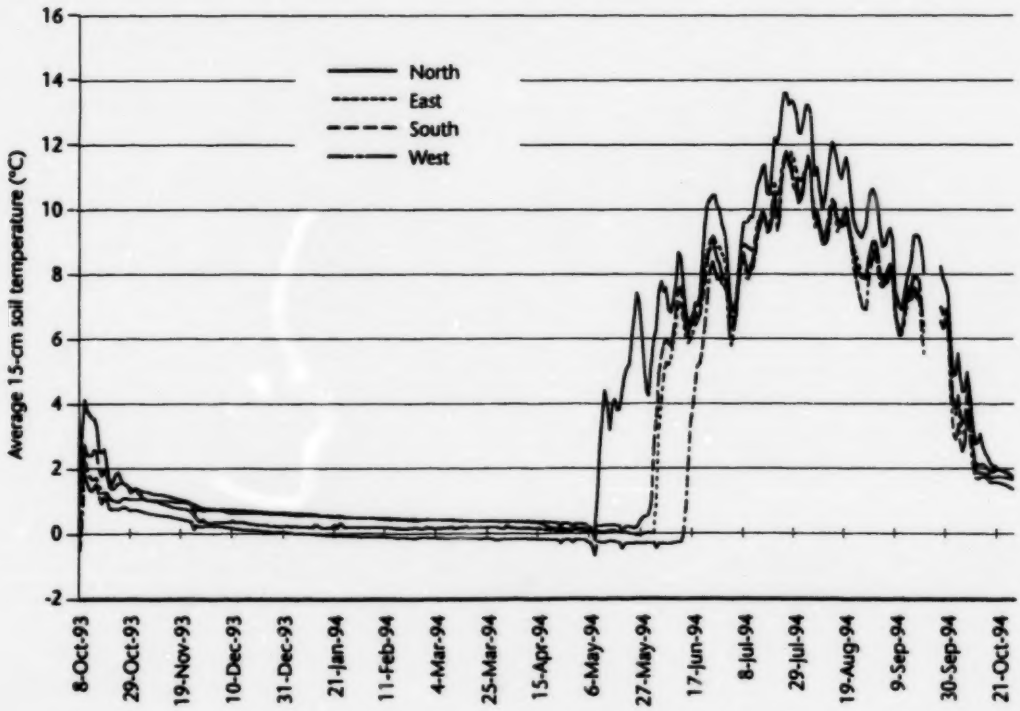


FIGURE 15 *Average daily 15-cm soil temperature in the 1.0 ha partial cut opening at Blackbear Creek at the stand edge on the north, east, south, and west locations.*

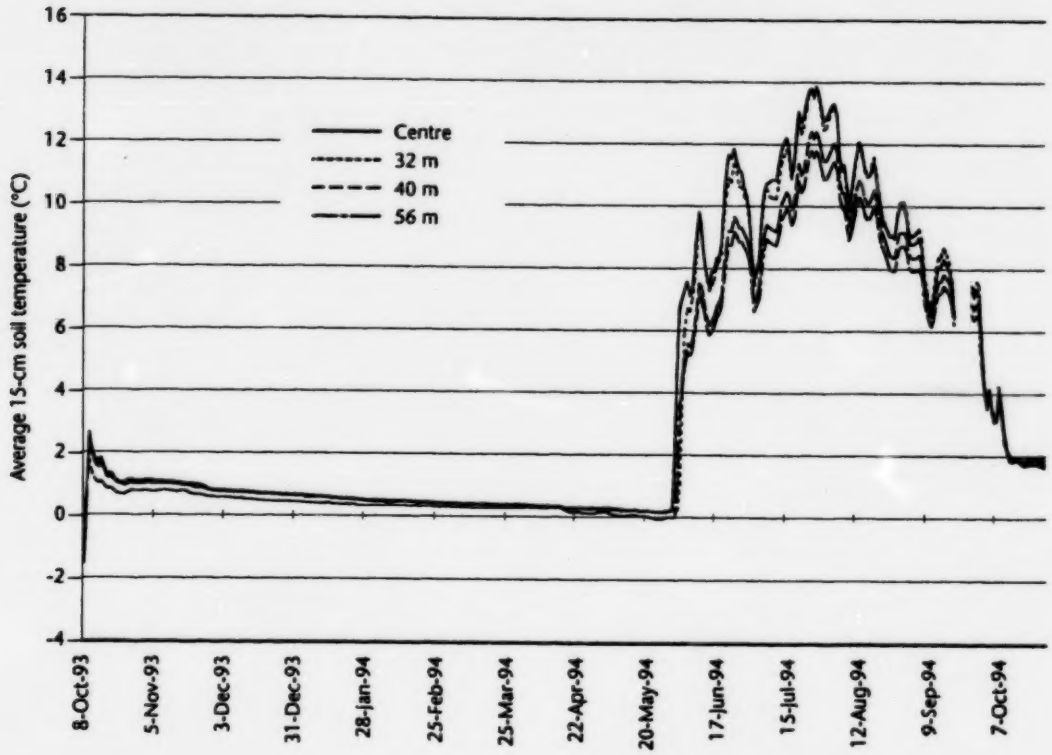


FIGURE 16 *Average daily 15-cm soil temperature in the 1.0 ha partial cut opening at Blackbear Creek at the plot centre, 32 m from the plot centre, 40 m from the plot centre, and at the western stand edge (east aspect).*

tures tended to be reduced. This was typical for transects in all directions from the plot centre.

The effects of distance from the stand edge and location within each opening on soil temperature are also seen in the comparison of the 15 cm depth soil temperature accumulated 5°C growing degree days. Table 8 shows the comparison of accumulated degree days between May 1 and September 30, 1994 in the 0.03-, 0.13-, and 1.0-ha plots. Note these probes are different from those used to monitor temperatures of the planting treatments.

There is a relationship between opening size and accumulated degree days, indicating that increased opening size and the resultant increase in direct solar radiation increases soil temperatures. Degree day accumulations in the untreated control, and the centre of the 0.03-, 0.13-, and 1.0-ha plots, were 404, 478, 523, and 570, respectively. Though data were not collected for the clearcut treatment in 1994, from 1995 through 1998 the accumulated degree days in the clearcut were typically nearly twice those in the uncut control treatment. The low number of degree days on the west, east, and north aspects on the large opening is probably due to accumulations of snow at these points combined with a slow melt rate, resulting in fewer snow-free days.

TABLE 8 *Effect of opening size and location within an opening on accumulated 5°C growing degree days between May 1 and September 30, 1994 in the 0.03, 0.13, and 1.0 ha partial cut treatments at Blackbear Creek*

| Aspect | S | W | N | E |
|---|---|---|---|---|
| Sensor location | N | E | S | W |
| **0.03 ha** | | | | |
| 0 m centre | 478 | 478 | 478 | 478 |
| 7 m | 410 | 377 | 371 | 421 |
| 10 m edge | 423 | 373 | 370 | 451 |
| **0.13 ha** | | | | |
| 0 m centre | 523 | 523 | 523 | 523 |
| 14 m | 515 | 507 | 505 | 502 |
| 20 m edge | 435 | 419 | 440 | 420 |
| **1.0 ha** | | | | |
| 0 m centre | 570 | 570 | 570 | 570 |
| 32 m | 572 | 553 | 458 | 518 |
| 40 m | 560 | 439 | 514 | 342 |
| 6 m edge | 548 | 390 | 389 | 334 |

## 4 CONCLUSIONS

The ESSFwc3 has a wet, cold climate. The growing season begins in early June after the snowpack finally melts, and lasts for only 5 months until late October, when snow cover resumes. Air temperatures are highly variable during the growing season, as a continuous series of Pacific frontal systems strongly influences local weather conditions. Average daily air temperatures typically range from 5 to 15°C during the mid-summer; however, extended rainless periods of up to a month in duration can result in warmer weather, with temperatures >25°C. During the winter, air temperatures typically range between 0 and -10°C, but can drop below -35°C when cold arctic air masses push southward.

Frequent precipitation is characteristic of the growing season. Afternoon convective rainshowers of 1–10 mm typically occur 3–5 times per week, and frontal systems often occur with up to 40 mm of rainfall. These humid air masses cool to the dew point at night and deposit dew on the forest canopy. The dewfall and precipitation result in continuous forest canopy wetting and drying cycles. The forest canopy remains dry on only about one-quarter of the days during the growing season.

Summer frost can occur at any time during the growing season in the ESSFwc3. The steep upper slopes at these three research sites allowed the radiatively cooled air to drain away to lower-lying areas. As a result, minimum night temperatures typically remained above -2°C during the growing season. Much lower air temperatures would likely occur on flatter ESSFwc3 sites or in microsites where cold air drainage concentrates and collects.

Soil temperatures at 15 cm depth remain near 0°C for most of the year under the deep snowpack. During the growing season, root zone temperatures typically remain between 6 and 12°C, but increase to as much as 16°C

during hot, dry periods. Approximately 400–600 5°C degree days normally accumulate during the growing season, although this varies considerably from year to year depending upon the weather conditions and when the snowpack melts. Soil and near-surface air temperatures and accumulated degree days were found to increase with increased forest canopy opening size. The accumulated degree days were found to be nearly double in the clearcut compared with the uncut forest. Planting microsites were also found to have quite different spatially and temporally variable soil thermal regimes. Some planting microsites (including scalping, rotten wood, and raised sites) were found to produce warmer soil temperatures, although results were varied between opening sizes. More intensive sampling is required to clarify the trends. In the 0.03-ha opening, the planting treatments had less of an effect on the soil temperature.

Atmospheric weather conditions and soil thermal regimes were found to vary considerably from year to year; however, conditions were found to be similar between sites in any given year. The effects of planting treatments also resulted in seemingly subtle differences in microclimate; however, even these small changes are likely to have significant effects on conifer survival and growth.

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